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EDUCATIONAL REVIEW

Fluid and electrolyte therapy: a primer

Aaron Friedman

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Abstract The prescription of fluid therapy in pediatrics is a common clinical event. The foundations that underpin such therapy should be understood by all clinicians involved in the short-term care of children. This article describes some important basic principles of fluid management.

Keywords Fluid and electrolyte management · Maintenance fluid therapy · Restoration fluid therapy

Introduction

The fundamentals governing fluid and electrolyte management in patients date to the 19th century. James Gamble, in his famous monograph on extracellular fluid, opens with a quote from Claude Bernard (1832), “The living organism does not really exist in the milieu exterieur (the atmosphere if it breathes, salt or fresh water if that is its element) but in the liquid milieu interieur formed by circulating organic liquid, which surrounds and bathes all tissue elements;... The stability of the milieu interieur is the primary condition for freedom and independence of existence; the mechanism which allows this is that which ensures in the milieu interieur the maintenance of all conditions necessary to the life of the elements.” [1]. In the first half of the 20th century work by Gamble [1] and Darrow and colleagues [2] defined the electrolyte content of extracellular, intracellular and interstitial fluid compartments.

Total body fluid, usually termed total body water, accounts for approximately 60% of total body weight (this can be 70% or higher in a newborn down to 50–55% in a mature woman). Total body water is distributed approximately two-thirds in the intracellular space and one-third in the extracellular space. The extracellular space is broken into two compartments: interstitial space, 75%, and plasma (vascular space), 25% (Fig. 1).

The electrolyte content within each compartment is distinctly different from that of the other. Table 1 describes the major electrolytes (ions) in body fluid compartments. The importance of the differences—extracellular fluid, containing sodium as its primary cation, with chloride and bicarbonate as its primary anions, and intracellular fluid, containing potassium as a primary cation, with phosphate as the primary anion—are crucial to our understanding of transcellular transport and essential to our understanding of the treatment of fluid and electrolyte disorders.

The simple elegance of Bernard’s explanation of extracellular fluid (milieu interieur), while appealing, fortunately, is not the way things are. The interstitial fluid component of extracellular fluid is actually a matrix, a collagen/gel substance that allow the interstitium to provide structural rigidity which resists gravity and can maintain structural integrity during extracellular volume depletion. The collagen/gel interstitial space, especially in skin and connective tissue, is an important reservoir of extracellular fluid [3].

Fluid and electrolyte therapy

Medical intervention is required if the site and composition of the extracellular environment is altered by disease or iatrogenic maneuvers. Fluid and electrolyte therapy requires as much care as the administration of any drug.

A. Friedman (✉)
Department of Pediatrics, University of Minnesota,
516 Delaware Street SE,
Minneapolis, MN 55455, USA
e-mail: alfried@umn.edu

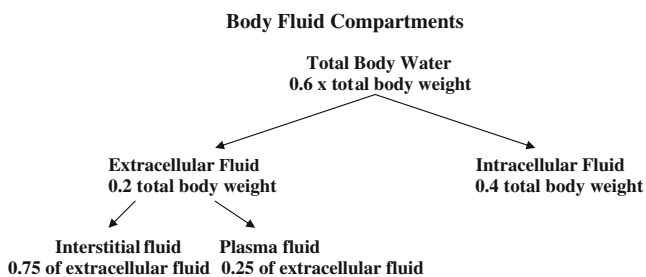


Fig. 1 Body fluid compartments

Clinicians have traditionally approached fluid therapy by first considering whether a patient is hypovolemic, euvolemic or hypervolemic. Second, are there electrolyte abnormalities, and, concomitantly, what is the pathophysiology of the patient's condition?

The focus for most clinicians is hypovolemia. In pediatrics this condition is most common and, for most of history and because of gastroenteritis, carried the greatest mortality rate. Table 2 describes the clinical features used to determine the percentage loss of body weight in a given clinical situation. These clinical signs provide an estimate of fluid loss. With hyponatremia, the degree of dehydration is often not as great as the appearance by clinical characteristics. With hypernatremia, the degree of dehydration is often greater than the clinical characteristics suggest. In the overwhelming majority of patients the fluid loss is primarily from the extracellular space. This is important, because the treatment for depletion of plasma volume or extracellular volume (dehydration) is the “rapid and generous restoration of extracellular fluid with 0.9% saline or Ringer’s solution.” (isotonic fluid) [4]. Depending on the severity of the depletion, repletion can be undertaken in as few as 30–60 minutes or up to 8–12 hours. Rapid restoration is generally considered as the replenishing of extracellular fluid volume; in some patients the clinical situation requires longer therapy (severe hyponatremia or severe hypernatremia). Patients with prolonged fluid loss (chronic diarrhea) will have intracellular fluid loss. This loss is the result of intracellular fluid moving into the depleted extracellular (especially interstitial) space. With generous extracellular fluid repletion, intracellular water will be restored. Isotonic saline solution rapidly enters the

interstitial space from plasma, usually in a matter of minutes. The movement of water from the interstitial space to the intracellular space, as occurs with hypernatremic dehydration, can also occur in minutes and explains why one must be careful with rate of change of osmolality in hypernatremic dehydration [5]. The same is true in the other direction—hyponatremic dehydration. The change in osmolality associated with the infusion of isotonic saline solution will result in a shift of water from the intracellular to the extracellular environment. This shift helps explain why, in the treatment of hyponatremia, the amount of sodium needed to return the extracellular sodium concentration (osmolality) fully to normal is quite substantial. Additional potassium may be necessary for full repletion of intracellular fluid.

Other considerations make rapid, generous, restoration of extracellular fluid volume the appropriate response to volume depletion. With volume depletion, two hormones play an important role in the ‘physiologic’ response: (1) aldosterone and (2) vasopressin (antidiuretic hormone). Aldosterone is released as a result of the renin–angiotensin–aldosterone (R-A-A) response to extracellular volume depletion. Rapid extracellular volume repletion will shut down the R-A-A response to volume depletion, reducing aldosterone secretion and decreasing potassium loss in urine. Vasopressin is released in response to volume (plasma and extracellular) depletion. This will result in decreased urine volume and avid water reabsorption by the kidney. This non-osmotic vasopressin release is an important reason why isotonic fluid should be used when there is extracellular volume depletion. Rapid extracellular volume repletion will shut off vasopressin release. Finally, with extracellular volume depletion, there is a redistribution of blood flow, with decreased flow to certain areas such as muscle and gut. This explains some of the difficulty in repleting volume depletion by oral administration of fluids. However, as pointed out by Hirschorn, with volume repletion (accomplished by rapid, generous, extracellular fluid repletion) it becomes easier to provide fluids orally as reabsorption from the gut is normalized [6].

Fluid and electrolyte restoration is the most acute focus for the clinician, but fluid therapy also includes consideration of ongoing losses and the provision of maintenance fluids. The provision of fluids for ongoing losses represents

Table 1 Electrolyte (and ion) composition in body fluids (ECF extracellular fluid, ICF intracellular fluid)

Ion	ECF	Interstitial	ICF
Sodium	135–145 mEq/l	145 mEq/l	10–20 mEq/l
Potassium	3.5–5.5 mEq/l	3.5–5.5 mEq/l	130–150 mEq/l
Chloride	95–105 mEq/l	100–115 mEq/l	<3 mEq/l
Bicarbonate	22–30 mEq/l	25–35 mEq/l	<10 mEq/l
Phosphate	2 mEq/l	2 mEq/l	110–120 mEq/l
Other	Albumin (plasma space)	No albumin	No albumin

Table 2 Severity of dehydration. Reproduced with permission from [12]. *BP* blood pressure, *Ant.* anterior, *mo* months

Characteristics			
Infants	Mild, 1–5%	Moderate, 6–9%	Severe, >10% (≥15%=shock)
Older children	Mild, 1–3%	Moderate, 3–6%	Severe, >6% (≥ 9%=shock)
Pulse	Full, normal	Rapid	Rapid, weak
Systolic BP	Normal	Normal, low	Very low
Urine output	Decreased	Decreased (<1 ml/kg per hour)	Oliguria
Buccal mucosa	Slightly dry	Dry	Parched
Ant. fontanel	Normal	Sunken	Markedly sunken
Eyes	Normal	Sunken	Markedly sunken
Skin turgor/capillary refill	Normal	Decreased	Markedly decreased
Skin	Normal	Cool	Cool, mottling, acrocyanosis
Infants<12 mo of age			

no more than a recognition that, for a patient who has suffered previous losses (vomiting, diarrhea, excessive urine losses) and where the process has not stopped, fluid loss will continue, even if the prior losses are restored. If significant, these losses are usually restored by measurement of the volume of the loss over a period of time (e.g. hours); if necessary, the electrolytes in the loss are measured, especially sodium, potassium chloride or bicarbonate, and provided back to the patient.

Maintenance fluids have been in the lexicon since a seminal publication over 50 years ago by Holliday and Segar [7]. They described a prescription for the intravenous administration of water and electrolytes to provide for the anticipated losses of water and electrolytes over the upcoming 24 hours in a euvolemic patient with normal renal function. Certain important principles should be remembered when one is thinking about maintenance therapy:

1. The volume prescribed is based on the principle that caloric expenditure predicts water requirements. This principle has been challenged, because the correlation between caloric expenditure, water requirements and body weight is not that tight; however, this relationship has been useful and has not yet been supplanted by more difficult to use formulae [8]. A clinically useful shortcut is to compare caloric requirements, thus water needs to weight. The commonly used equation is: 100 ml/kg per 24 h for weights of 2–10 kg (premature infants have different requirements); for weights of 11–20 kg, 1,000 ml plus 50 ml/kg per 24 h for each kilogram between 11 kg and 20 kg, and for children over 20 kg the volume prescribed is 1,500 ml plus 20 ml/kg per 24 h for each kilogram between 21 kg and 70 kg. The fluid recommendation is divided roughly so that 50% of the recommendation is to make up for

urine loss and 50% for water losses in respiration, perspiration and loss in stool.

2. The electrolytes prescription as described by Holliday and Segar is sodium 2–3 mEq/100 ml of fluid provided, potassium 2 meq/100 ml of fluid provided. The usual anion recommended is chloride. This is a hypotonic solution.
3. Holliday and Segar recognized the need to consider the individual patient's situation. "As with any method, understanding the limitations of and exceptions to the system is required. Even more essential is the clinical judgment to modify the system as circumstances dictate." [7]. Further, in a publication in 1962, it was recognized that patients with low urine volume and high urine osmolality cannot receive the volume prescribed because of the risk of hyponatremia. This recommendation recognized the risk of non-osmotic vasopressin release and reduced the total volume of the hypotonic solution prescribed. The recommendation in that publication is to reduce the maintenance fluid prescription by at least 25% and up to 50% [9]. Recently, a new approach to maintenance fluid therapy has been recommended. This involves using the same volume prescription as that of Holliday and Segar, but the fluid recommended is isotonic saline solution [10]. In a systematic review in 2006 Choong et al. conclude: "Our current responsibility, however, is to refrain from adopting a "new standard of care", until rigorous clinical trials comparing the safety and effectiveness of different IV fluid regimens in children have been completed." [11].
4. Maintenance fluid therapy is not designed to be used for anything other than maintenance. Again, from the 1957 publication, Holliday and Segar state, "... it should be emphasized that these figures provide only maintenance needs of water. It is beyond the scope of

this paper to consider repair of deficit and replacement of continuing abnormal losses. These must be considered separately.”

Conclusion

The rational intervention into fluid and electrolyte abnormalities is best orchestrated by a physician knowledgeable in fluid and electrolyte physiology who understands the root cause(s) of the derangement and understands the pathophysiology of the derangement and the best approach to restoring fluid and electrolyte homeostasis. Normal compartment size and make up of body fluid, movement of fluid between the compartments and the prescription for overcoming derangements are essential for appropriate short- and long-term fluid and electrolyte management.

Questions

(Answers appear following the reference list)

1. The extracellular fluid (ECF) and intracellular fluid (ICF) compartments in total body water are normally in a ratio of (ECF:ICF):
 - a. 1:1
 - b. 2:1
 - c. 1:2
 - d. 1:4
2. The dominant extracellular cation and anion are:
 - a. Sodium and bicarbonate
 - b. Potassium and chloride
 - c. Potassium and phosphate
 - d. Sodium and chloride
3. The dominant intracellular cation and anion are:
 - a. Sodium and bicarbonate
 - b. Potassium and phosphate
 - c. Sodium and chloride
 - d. Potassium and chloride
4. The recommended replacement for extracellular volume fluid loss is:
 - a. Isotonic (normal) saline solution
 - b. Dextrose and one-fourth normal saline solution
 - c. Dextrose and one-half normal saline solution
 - d. One-half normal saline solution plus 20 mEq potassium chloride per liter

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Answers:

1. c.
2. d.
3. b.
4. a.